Substrate Effect on X-band Design of End-Wall Double Slit Microstrip-to-Waveguide Splitter

Hadi Aliakbarian[#1], Amin Enayati[#*2], Walter de Raedt[*3] Guy A.E. Vandenbosch[#4]

[#] *ESAT, Katholieke Universiteit Leuven*
Kasteelpark Arenberg 10, B- 3001 Leuven, Belgium
[1]`hadi.aliakbarian@esat.kuleuven.be`
[4]`guy.vandenbosch@esat.kuleuven.be`

[*]*IMEC*
Kapeldreef 75, B-3001 Leuven, Belgium
[2]`amin.enayati@imec.be`
[3]`walter.deraedt@imec.be`

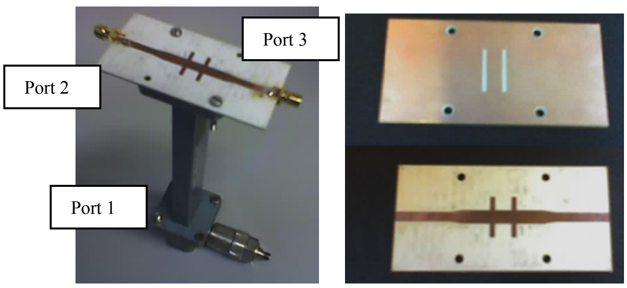
***Abstract*— End-wall waveguide-to-microstrip splitters are highly favourable to feed series' fed microstrip arrays. The presented topology of a double slot microstrip transition clearly shows distinct advantages. To investigate the effect of substrate material and thickness on this kind of transition three different substrates are used for the transition design. Simulation and measurement results are compared. Finally, one of the designs is applied to feed an antenna array.**

I. Introduction

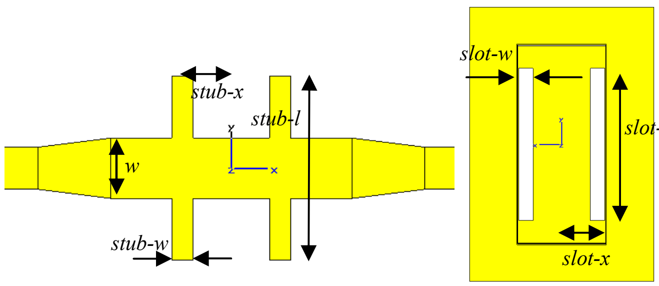
Although it is highly desirable to select planar structures due to their lower cost and complexity and also their low profile, metal hollow waveguides are still important functional parts in many circuits, especially at millimetre frequencies. These waveguides are usually needed in antenna feeds, high-Q components, duplexers, and low phase noise oscillators. At these higher frequencies, the waveguide bulkiness becomes less of a factor and its losses are smaller than those of a microstrip line. Thus, a well-designed practical transition from a waveguide to a microstrip line becomes an important point.

Several types of transitions from waveguide to microstrip line have been reported in literature [1-2], but most of them suffer from several disadvantages such as manufacturing complexity and relatively large bulkiness. Also, it is difficult to integrate them with the planar circuits. Our goal was mainly to provide a feeding network for a series fed microstrip array using a good transition with 180-degrees phase shift between the two microstrip output ports, but a few of the previous transitions are useful for feeding such planar antenna arrays [3-5]. The symmetrical structure of the transition in a splitter format guarantees a non-rotated radiation pattern while series fed microstrip arrays suffer from this problem. Thus, we use a recently introduced class of splitter/combiner transitions to overcome the disadvantages mentioned and to design a feeding network for a 1x2 array.

The transition which has been introduced before [6] consists of an end-wall connection between a simple metal waveguide and a double sided etched substrate, shown in Fig.1, where the substrate and waveguide are physically separated. There is a double slit in the ground of the substrate, coupling the wave to two microstrip ports. Also, two stubs are added to the microstrip line. This transition can be terminated in one port and serve as a single-end transition, or it can be designed as a two-way power splitter/combiner. Although the final transmission loss is increased about 0.5 dB compared to the best previous solutions, it lowers the cost, size and complexity, and improves the bandwidth of the transition.



(a) 3D view of the manufactured antenna



(b) Top stub view (c) bottom slot view

Fig. 1 Proposed double-slit end-wall transition

However, there are some limitations on the coupling bandwidth of these transitions which depend on the thickness and dielectric constant of the substrate. The first limitation comes from the fact that the bandwidth of the hollow waveguide is limited. Moreover, the functionality of the splitter is highly similar to a Tee-junction. However the difference here is that having a very thick substrate increases radiation losses and having a very thin one makes it very difficult to match the splitter at the waveguide port.

In this paper, the design of three transitions on different substrates with different permittivities and thicknesses is discussed in section 2. In section 3, the transition applied to an antenna is presented. Finally, the paper is concluded in section 4.

TABLE I
DIMENSIONS OF THE TRANSITIONS ON RO4003 – RT5880 – RT6010

WAVEGUIDE WR90: 22.86 MM X 1.016 MM

Variable (in mm)	***RT5880*** *1.524 mm*	***RO4003*** *1.524 mm*	***RO4003*** *0.813 mm*
Slot-l	16.84	16.8	19.17
Slot-w	1.37	1.5	1.77
Slot-x	3.76	3.63	3.15
Stub-l	7.4	7.64	7.43
Stub-w	1.77	1.75	3.36
Stub-x	3.45	4.04	4.01
W	4.69	5	4.99

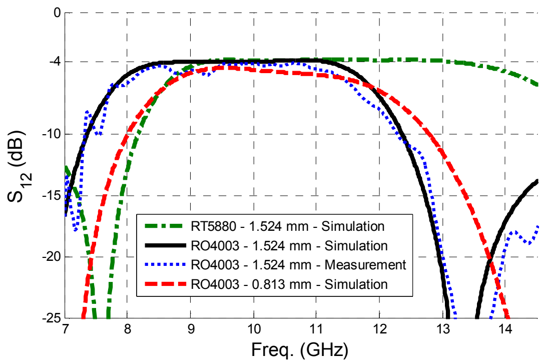


Fig. 2 Simulation results of the coupling (S_{21}) for the designed splitters

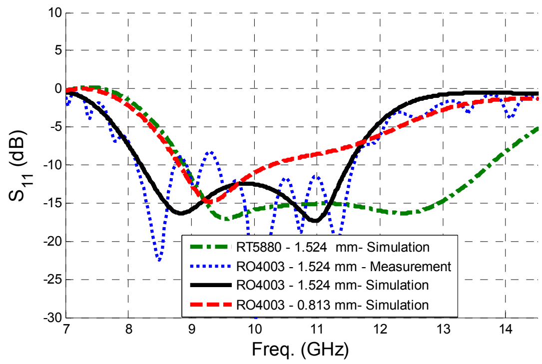


Fig. 3 Simulation results of return loss (S_{11}) for the designed splitters

II. TRANSITION DESIGN WITH DEFFERENCT SUBSTRATES

To investigate the effect of substrates on the performance of the transition, three different substrates, RT5880 (t = 1.524 mm, ε =2.2), RO4003C (t = 1.524 mm, ε =3.38), and RO4003C (t = 0.813 mm, ε =3.38) have been used. After the designs are completed and optimized, the 2-layer substrates are etched using PCB technology and a WR90 waveguide is connected to it. An X band WR90 waveguide works between 8.2 and 12.4 GHz (standard working range) with a bandwidth of 40%. Thus, the bandwidth of the transition is limited by the bandwidth of the waveguide.

The results for all three optimized designs are sketched in Figure 1 and Figure 2 for S_{11} (return loss) and S_{12} (coupling) respectively. The starting point was to try to keep wideband operation. In fact, the transition could be designed so that coupling levels better than -4 dB are obtained, but then wideband operation is lost. The design on RO-4003 with 0.813 mm thickness is wideband but coupling level doesn't get better than -5 dB. Using RO-4003 with 1.524 mm thickness, the coupling easily is improved to -4 dB with an acceptable level of ripple within the 26 % bandwidth. The corresponding return loss for these designs in Figure 2 demonstrates that the thicker substrate is matched better as it was expected and stated in section 1.

In Figure 1, solid line and dash-point line are couplings for 1.524 mm respectively on R0 4003 and RT 5880 substrates. The bandwidth for a coupling magnitude of more than -4 dB for the two latter is about 26 % and 35 % respectively, which is excellent for this kind of splitter. It shows that the design for lower dielectric constants can be more wideband. The return loss of the transition within the band is always better than -10 dB.

As it can be seen in Fig 1.a, a double sided board is etched on both sides and then pasted to the waveguide. Measurement results in both figure 1 and 2 are compared with simulations, The most obvious discrepancy are the oscillations, mainly due to the effects of connectors, soldering, and small gaps between waveguide flange and the board.

It is worthwhile pointing out that going up in frequency resembles using thicker substrates. Consequently, as the coupling and return loss of the thicker substrates are superior, it can be understood that the design procedure is much easier for example at millimetre wave frequencies.

III. ANTENNA EXAMPLE

The substrate RO4003C (t = 0.813 mm, ε =3.38) is chosen for the 1x2 antenna array shown in Figure 4. The antenna is a dual band structure designed so that it shows a non-rotating pattern at the beginning and end of the band, 9 and 10.5 GHz respectively. Each element consists of a square patch and a complementary half ring which is responsible for the second band resonance. The elements are placed near the matching stubs of the transition.

Again, the 2-layer board is pasted to the waveguide. The return loss measurement result in figure 5 is compared with the simulation. A negligible frequency shift is observed. More importantly, the peak of the radiation pattern should not change from broad side. The simulation results from CST microwave studio along with measurement results confirm the none-rotating beam at the broadside direction at 9 GHz and 10.5 GHz, respectively. This validates the desired out of phase characteristic of the transition for the whole working band. Figure 6 shows the radiation pattern at 9 GHz and figure 7 shows the pattern at 10.5 GHz in the E plane.

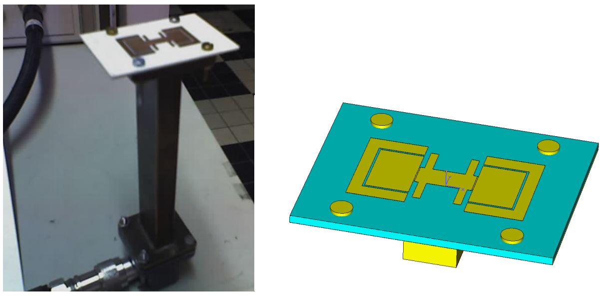


Fig. 4 1x2 array based on the transition design in section 2

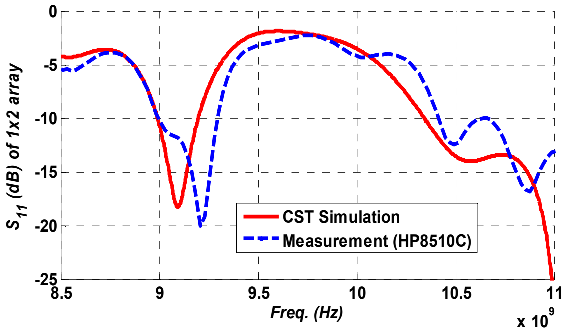


Fig. 5 measurement and simulation return loss for the 1x2 array

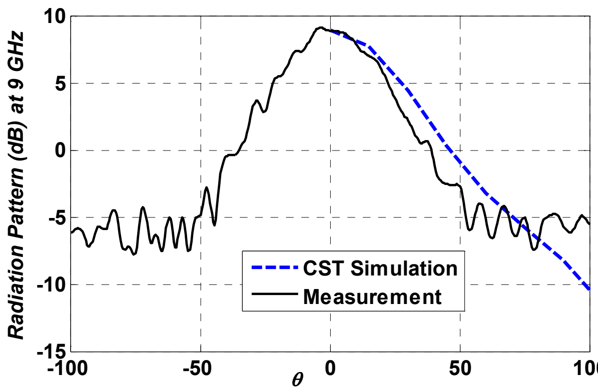


Fig. 7 Radiation pattern results of the splitter used for array feeding at 9 GHz

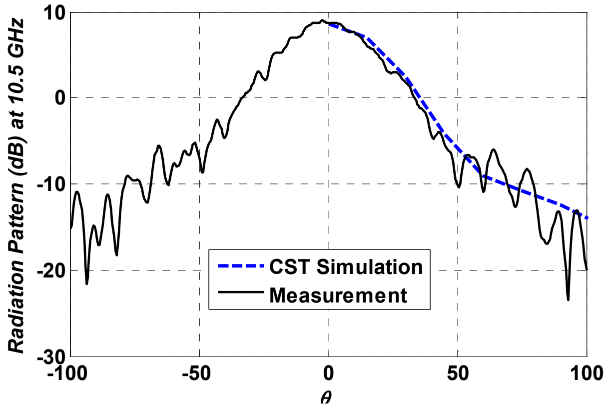


Fig. 6 Radiation pattern results of the splitter used for array feeding at 10.5 GHz

IV. Conclusions

The presented double slit transition designs in X-band show that a splitter on a thicker substrate with lower permittivity has a better performance. This helps us to design better transitions at higher frequencies, at which the thickness is relatively high. As the transition is appropriate for series' fed microstrip arrays, one of the designs is applied to a dual band 1x2 array. The simulation and measurement results confirm wideband operation of the transition and a non-rotating pattern of the array in both bands.

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